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The criterion for the optimal sampling of a copper thermistor for atmospheric measurements under normal conditions☆

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Abstract

In this paper a new parameter is suggested as a criterion for selecting the optimal value of the copper thermal resistance in temperature measurements in the atmosphere under normal conditions. The proposed parameter is directly proportional to the sensitivity of thermal resistance and inversely proportional to the product of 'dead' resistance and 'dead' temperature (the product of errors of temperature and resistance when their determination). It has been shown through the example of 4 samples that this criterion is convenient. For one of the thermal resistance this parameter is higher in the investigated range of temperatures.

Keywords: Selection criterion; Copper thermistor; Temperature measurement; 'Dead' resistance; 'Dead' temperature.

There is currently a wide range of experimental studies dedicated to measuring electrical as well as non-electrical quantities; such studies typically involve using platinum and copper thermal resistances (TR). After special calibrations, a TR is used as a measuring transducer changing its resistance depending on various types of effects, including the thermal. Conductor resistance is the quantity measured.

Experimental studies requiring precision temperature measurements also often use platinum and copper TRs. After calibration the TR can be used to obtain temperature from the measured magnitude of their resistance.

For a copper TR used according to the GOST 6651-94 standard [1], the ratio of its resistances at 100 and 0 °C, respectively, should be

$$\frac{R(100\,^\circ\mathrm{C})}{R(0\,^\circ\mathrm{C})} = 1.427 \pm 0.001. \tag{1}$$

If we use the well-known linear relationship between resistance and temperature

$$R(t) = R_0 + at, \tag{2}$$

where R_0 is the conductor resistance at the temperature $t = 0\,^\circ$C and a is the slope following the dependence

$$a = R_0\alpha \tag{3}$$

(α is the temperature coefficient of resistance), and write the formula (2) for the same temperatures, we

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can obtain this ratio:

$$\frac{R(100\,^{\circ}\mathrm{C})}{R(0\,^{\circ}\mathrm{C})} = 1 + \alpha \cdot 100\,^{\circ}\mathrm{C}. \tag{4}$$

If we compare the right parts of the formulae (1) and (4), we can obtain the following value of the temperature coefficient of resistance:

$$\alpha = 0.00427 \pm 0.00001. \tag{5}$$

The GOST R 8.625-2006 standard [2] that came into effect on January 1, 2008, included instead of the ratio (1) a temperature coefficient of resistance whose value for copper TR should be 0.00428 $(^{\circ}\mathrm{C})^{-1}$ (with no tolerance limit specified).

The next GOST standard issued in 2009 [3] contained, aside from this quantity, copper TR with a temperature coefficient of resistance $\alpha = 0.00426$ $(^{\circ}\mathrm{C})^{-1}$. Thus, currently, the temperature coefficient of resistance for TR conforming to the GOST standard should actually have the previous value including the tolerance limit (5).

The latter adjustment is most likely due to the fact that various additions, e.g., nickel, tin, and silver, are used as additions in copper wire production (the wire serves as a TR). Naturally, because of this circumstance, copper TR may have varying temperature coefficients of resistance (for example, for imported TR it is equal to the lower limit of the value (5) [3]).

On the other hand, if we examine sensitivity of TR (a characteristic indicating the rate at which resistance changes with a change in temperature) that obviously depends on the slope a, then the formula (3), aside from the temperature coefficient α, should also include the resistance value R_0.

This being said, the question that needs to be addressed is whether a special criterion could be formulated to help selected the optimal resistance value of a copper TR for performing thermal measurements.

This paper is dedicated to the study carried out with this goal in mind.

Four samples of enameled copper wire 0.1 mm in diameter made by the Velleman company (Belgium) were used for the study; the samples differed in resistance values by about a factor of 2 (see Table 1 for resistance values at 0 °C and 20 °C; they are denoted as R_0 and R_{20}, respectively).

The wire was wound around a wooden 440 × 230 × 20 mm-sized frame. The numerical value of TR was measured using the Wheatstone bridge whose independent arms and diagonal included R-33 resistance boxes and a V7-35 digital voltmeter, respectively. A constant stabilized voltage of 9 V was applied to the bridge input. The temperature t was measured in the laboratory under normal conditions (15–25) °C by a thermometer with a resolution of 0.1 °C; it varied naturally over a period of time from morning to evening. A water or an oil radiator was occasionally used to heat the laboratory. The thermal equilibrium between the TR and the measurement environment was monitored via the $R(t)$ dependence plot; the equilibrium was assumed to be reached if no distinct dips in the resistance of some temperature region could be found in the plot (the dips appeared if the sample did not have enough time to heat up).

Table 1
The obtained experimental data.

Parameter	Parameter value for the sample			
	1	2	3	4
R_0, kΩ	0.5378	0.8585	1.5693	3.1738
R_{20}, kΩ	0.5828	0.9293	1.7035	3.4372
ΔR_0, Ω	0.09	0.12	0.19	0.49
R_D, Ω	1.2	1.9	3.4	6.9
a, $\Omega\cdot(^{\circ}\mathrm{C})^{-1}$	2.260	3.540	6.710	13.170
Δa, $\Omega\cdot(^{\circ}\mathrm{C})^{-1}$	0.005	0.005	0.010	0.025
α, 10^{-3} $(^{\circ}\mathrm{C})^{-1}$	4.20	4.12	4.20	4.15
K, $(^{\circ}\mathrm{C})^{-2}$	3.60	3.50	3.90	3.60
K_0, $(^{\circ}\mathrm{C})^{-2}$	631	870	1247	722

The experimental results of the dependence (2) obtained in the above-described normal conditions were processed using the linear ordinary least-squares method (OLS); 1720 measurements were performed for each sample. The OLS method was used to find the slope a and the free term R_0 (recall that it corresponds to the thermal resistance value at 0 °C), with their mean-square deviations (Δa and ΔR_0, respectively, see Table 1). The instrument error of the resistance box for the chosen conditions was determined by its accuracy class which was 0.2%

Evidently, the efficiency of TR should be directly proportional to its sensitivity (see above) and inversely proportional to its ‘dead’ resistance multiplied per its ‘dead’ temperature (see below). Therefore, the parameter that we suggest using for determining the criterion for sampling the optimal value of the thermal resistance is the quantity

$$K = \frac{a}{R_D t_D}, \tag{6}$$

where $a = \frac{\Delta R}{\Delta t}$ is the sensitivity of TR (determined by the slope of the linear function $R(t)$ to the abscissa axis t); R_D is the ‘dead’ resistance (DR); t_D is the ‘dead’ temperature (DT).

The resistance error at 20 °C taking into account the accuracy class of the resistance box was used as the DR R_D. It turned out to be higher than TR mean-square deviation ΔR_0 by about an order of magnitude (see Table 1) in the measured temperature range. We should note that for a resistance box with a higher accuracy class, e.g., MSR-60 M (accuracy class 0.02%), the obtained DR appear to be comparable to the corresponding mean-square deviations. The temperature error at 20 °C (with a certain value) with a fixed resistance at the same temperature was used as the DT t_D. If the error at 20 °C is taken as the thermometer error, then the specific behaviors of the thermistors cannot be traced, since they all have the same thermometer error, which is 0.05 °C. This is why the DT was interpreted as the product of the DR multiplied by the cotangent of the angle (a^{-1}) between the obtained experimental dependence $R(t)$ and the abscissa axis t, i.e.,

$$t_D = R_D \cdot a^{-1}. \tag{7}$$

By substituting the formula (7) into the expression for the criterion (6), we obtain that

$$K = (a/R_D)^2. \tag{8}$$

The experimental results obtained are listed in Table 1. The following conclusions can be made from analyzing it.

1. The errors obtained from the formulae for indirect measurements [4], taking into account the instrument error for the temperature coefficient α and the parameter K, were, respectively, $1.1 \cdot 10^{-4}$ (°C)$^{-1}$ and 0.05 (°C)$^{-2}$, while for the parameter K_0, taking into account the values obtained through the OLS method, the error was lower than the quantity itself by over two orders of magnitude for all samples.
2. Taking into account the errors mentioned in 1, the temperature coefficients α match for all samples, and, except for the second one which is different in the third significant digit, they match the similar value (5) from the currently existing GOST standard.
3. The parameter K has the highest value for the third sample, while the first, the second, and the fourth one have the same values of the parameter.
4. If the mean-square deviation ΔR_0 for the free term of the OLS method is taken as a DR, and the corresponding DT is found using the ratio (7), then, through substitution into the expression (8), the parameter K_0 for the third sample is found to be significantly higher compared to TR of other samples.
5. Based on 3 and 4, we can conclude that the optimal result for the four samples of copper TR from the ones obtained under the chosen conditions during the thermal measurements is the resistance value of the third sample.

Thus, the proposed parameter $K(K_0)$ can serve as a convenient and reliable criterion for sampling the optimal value of a copper TR during thermal measurements in the atmosphere under normal conditions.

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